Striped bass analysis for the CALFED Through Delta Alternative.
Lee W. Miller
California Department of Fish and Game
Bay Delta Division

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1. What is the relationship between the number of days of diversion curtailment at Hood and the fraction of striped bass eggs and larvae protected?

An analysis of the abundance of eggs in the Sacramento River above Hood by year and over all years was completed for the years 1972, 1973, 1975, 1984-1986, 1990-1994. These are the years when the Sacramento River egg and larva sampling was conducted above Sacramento where the spawning grounds are located. In most years sampling was every two days, whereas in 1994 sampling was done every four days. For all years combined, 80 percent of the eggs were sampled between julday (day number post January 1) 128 (May 8) and julday 157 (June 6); similarly the period when 90 percent of the eggs were captured, extends from julday day 125 (May 5) to julday day 160 (June 9) (Figure 1). Annual shifts in the time of spawning occur because spawning is generally later in high flow years and earlier in low flow years. The eggs spawned outside of this time period may make important contributions to the population, i.e., survival may be disproportional to egg abundance, but this is unknown and such success would be dependent on the more favorable survival conditions. Since this analysis includes several flow year types, these results reflect average conditions. The distribution of spawning and the midpoint of spawning for individual years is summarized in Table 1. Monitoring of spawning would provide for limiting of exports for those time intervals when spawning episodes occur.
   Curtailment of exports during this period would result in most eggs having an opportunity to be transported to the lower Sacramento River or Suisun Bay depending on Sacramento River flows and the numbers diverted at Georgiana and Three Mile Slough.

2. What are the relative priorities and magnitude of curtailments to minimize the diversion losses for striped bass at the existing pumps? Would that change for Alternative 2?

There are two ways to minimize the diversion losses of striped bass. One is to curtail or reduce export pumping for time periods when the fish are most vulnerable to entrainment and the other is to transport fish downstream areas away from the zone of influence of the pumps. The period when absolute numbers are most vulnerable is during the months of May-July (Figure 2). In critical and dry years, the timing of fish salvage appears to be shifted about a month earlier with large catches in May with peak salvage in June in comparison to normal and wet years when large catches begin in June and salvage peaks in July. Salvage losses due to screen inefficiency occurs during egg and larva stages as well as losses of larger young bass due to predation and other factors.

A major question is the time value of the fish in regard to curtailing export entrainment. If exports are curtailed during the egg and larva and early juvenile stages but increased during later juvenile stages, is there an increase or decrease in overall survival and recruitment? An analysis using a life table with yearly equivalent losses would be needed to evaluate the population effects of diversion timing. I did not make any attempt to perform such analyses or explore the feasibility of doing so.

3. What is the relationship between bass survival and the magnitude and duration of flow in the Sacramento River below Hood?

This question was addressed with two approaches. A previous analysis done for WRINT Exhibit #2, used cohort analysis of survival between the egg stage and 6 mm larva stage. Both of these stages were measured in the field. This analysis indicated that flows above 13,000 cfs resulted in higher survival. Additionally, I examined survival of striped bass from the egg stage to the 6-mm larva stage based on annual averages. This was done by dividing the 6 mm abundance indices from the striped bass egg and larva surveys by the estimates of adult egg production. The latter estimate was made by multiplying Petersen population estimates by the estimated average fecundity of each age class and summing over all age classes to estimate total potential egg production for each year.

Survival was significantly positively correlated with total inflow, Sacramento River flow, and Delta outflow for periods April to June and April to July (Table 2). Survival increases linearly with flow (Figure 3). This analysis corroborates the cohort survival and flow analysis described above which indicated flows greater than 13,000 cfs produced higher survivals.

4. What is the relationship between magnitude and duration of flow in the San Joaquin River and the proportion of striped bass young moved out of the influence of the CVP/SWP pumps?

Higher San Joaquin River flows affect the survival of striped bass by moving bass downstream from the influence of export pumping. I used the estimates of the percent reduction in 20 mm striped bass abundance. These estimates were made in only four years because data upon which they are based was only available for four years. The percent reduction in 20-mm striped bass was estimated as the cumulative effect of entrainment losses based on egg and larva sampling in the estuary and in the south Delta in years 1985, 1986, 1988 and 1989 (SWRCB Exhibit 25 and WRINT EXHIBIT#2, SWRCB, 1992) to compare with estimates of net flow of the San Joaquin River at Jersey Point (Department of Water Resources, DAYFLOW data base). The relationship between flow and the percent reduction in the population is significant (Figure 4). The relationship may not be linear over the range of flow values but its parameters are unknown because data are lacking between zero and 8000 cfs. A power function transformation of the percent reduction(percent reduction^{-2}) produced a strongly linear relationship ($r=0.999$). It is evident from this analysis that positive flow in the San Joaquin River increases the survival of fish to 20 mm.

I also examined the flows which are required to move fish out of the Delta by calculating

the fraction of the population that was west of the Delta and relating this fraction to flows on an annual basis. Striped bass larvae and juveniles are moved west of the Delta by increased flows. The fraction of the larval striped bass west of the Delta for the size range 6-10 mm increased with increasing April-July Delta outflow (Figure 5).   At 10,000 cfs about 30 percent of the larval striped bass are west of the Delta, whereas at flows less than 8,000 cfs less than 10 percent are west of the Delta. Young striped bass abundance in Suisun Bay is generally over one-half the total when flows are above 10,000 cfs (Figure 6). To maximize the fraction of the striped bass population west of the Delta, April-July Delta outflow in the range of 20,000-26,000 cfs would be required for larval striped bass and 10,000 cfs for juveniles. Criteria for using these flow relationships in determining operations to improve conditions for striped bass need to be developed. Flows over the period April to July should be apportioned in relationship to their historic relationship. Historically April flows are much higher than July flows and May and June flows fall in between. Since all these flows are autocorrelated, it is not possible to separate them in importance. The ratio of these spring flows to each other along with their standard errors is summarized in Table 3.

Striped bass abundance and distribution are both related to Delta outflow and therefore distribution and abundance are related. The abundance of striped bass for years before 1977 increased with increases in the fraction of the population west of the Delta (R^2=0.274 ,p=0.03). However, since 1977, this relationship is weaker and not statistically significant (R^2= 0.15, p=0.09) (Figure 7). The most apparent reason for this change is that egg production appears to be the dominant variable driving young bass production in recent years such as 1996 when egg production is so low (Figure 8). Consequently there can only be a small response or no response to the high flows.

Survival between egg production and the 38-mm index is also related to the fraction of fish that are located west of the Delta. Even though the 38-mm index is less responsive to Delta outflow in recent years, the survival between egg production and the 38-mm index is related to the fraction of the index which is downstream (Figure 9).

Table 1. The dates which bracket the occurrence of 80 percent of the egg abundance in the Sacramento River above Hood and the mid-date of spawning for years of record 1972-1994.

Year	Julday 1	Date	Julday 2	Date	Total days for 80 % of spawning	mid-date (50 %)	Spawning Mid-date
1972	129	May 9	153	June 2	24	133	May 13
1973	127	May 7	155	June 4	28	147	May 27
1975	143	May 23	163	June 12	20	155	June 4
1977	133	May 13	151	May 31	18	137	May 17
1984	126	May 6	152	June 1	26	132	May 12
1985	132	May 12	156	June 5	24	134	May 14
1986	130	May 10	152	June 1	22	140	May 20
1990	118	April 28	160	June 9	42	138	May 18
1991	126	May 6	154	June 3	28	144	May 24
1992	106	April 16	138	May 18	32	116	April 26
1993	118	April 28	158	June 7	40	130	May 10
1994	106	April 16	146	May 26	40	118	April 28

Table 2. Correlations between egg to 6 mm striped bass survival and mean flows.

flows	r	p
Log10 April-July Delta inflow	0.70066	0.0036
Log10 April-July Delta outflow	0.67958	0.0053
Log10 April-July Sacramento river flow	0.71470	0.0028
Log10 April-June Delta inflow	0.68515	0.0048
Log10 April-June Delta outflow	0.66882	0.0064
Log10 April-June Sacramento River flow	0.69879	0.0038

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Table 3. The mean ratios of the monthly flows for April to July and the standard error of ratios for years 1956-1997 based on DAYFLOW flow data.

Year type	number of years	mean April outflow	ratio April-May	ratio May-June	ratio June - July	standard error of April-May ratio	Standard error of May-June ratio	Standard error of June-July ratio
Above normal	3	22,042	1.36	1.23	1.91	0.19	0.16	0.57
Below normal	6	14,170	1.39	2.45	2.34	0.17	0.38	0.94
Critical	8	5,112	1.41	1.38	0.98	0.23	0.13	0.06
Dry	7	9,015	1.28	2.42	1.17	0.11	0.54	0.20
Wet	18	45,957	1.65	1.90	2.18	0.20	0.19	0.23
overall	42	36,942	1.48	1.91	1.78	0.10	0.14	0.18